A Search For Planet Nine With Far-Infrared All-Sky Surveys Data

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What is Planet Nine?

In 2016, the analytic and modeling simulation research of Batygin and Brown suggests that a giant distant planet in the outer solar system may be the orbit perturber and the reason for the strong clustering of distant Kuiper Belt Objects (KBOs) [1]. This planet, which is also known as Planet Nine or Planet X, was predicted to have a very long orbital period of 10,000 – 20,000 Earth years. However, the existence of Planet Nine has not been confirmed by observations.

Motivation

The sunlight reflected by Planet Nine degenerates by d^{-4}, while its thermal radiation only decreases by d^{-2}, where d is the distance from Sun to Planet Nine [2]. As a result, sources from optical surveys are 100 times fainter than those from infrared surveys. On the other hand, infrared light is difficult to be detected by ground-based telescopes due to the Earth's atmosphere. Therefore, infrared surveys using space telescopes such as IRAS and AKARI are more advantageous to find Planet Nine.

Method and Procedure

Catalogue	Date	Total sources	Wavelengths (μm)	Depth (Jy)	Resolution (arcsec)
IRAS-PSC	Jun. 1983	245,889	12, 25, 60, 100	0.6	60
IRAS-FSC	Jun. 1983	173,044	12, 25, 60, 100	0.2	
IRAS-PSCR	Jun. 1983	372,753	12, 25, 60, 100		
IRAS-FSCR	Jun. 1983	593,516	12, 25, 60, 100		
AKARI-BSC	Nov. 2006	996,342	65, 90, 140, 160	0.44	39

Expected flux and proper motion

↓

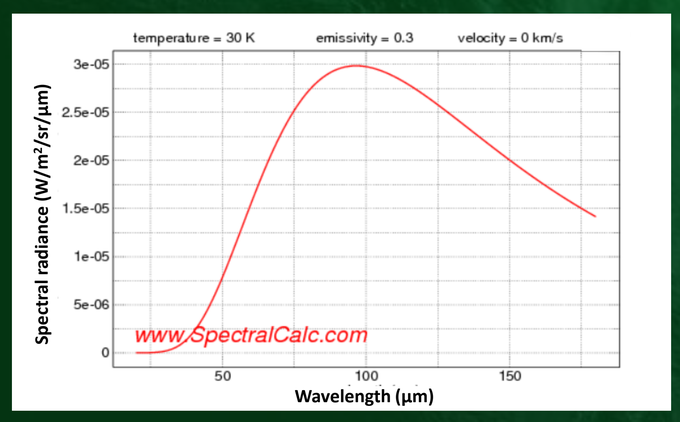
Matched sources between IRAS and AKARI

↓

Position and flux selections

↓

Final list of candidates

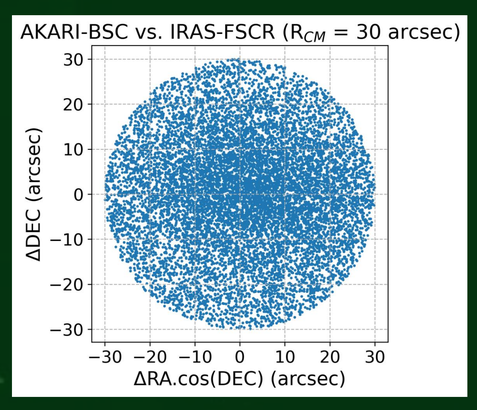


➢ *Spectral radiance of Planet Nine at different wavelengths.*

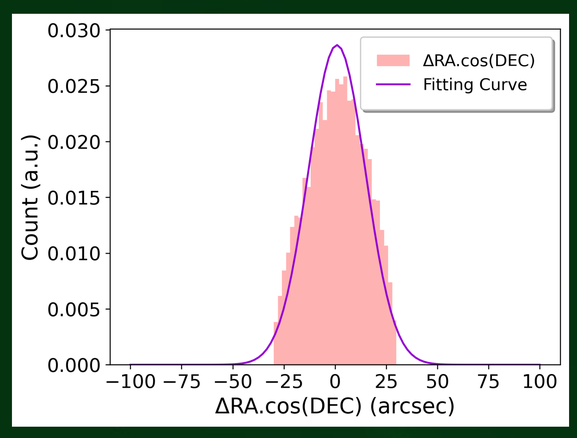
- We used data from IRAS and AKARI surveys, whose operating time was separated by 23.4 years.
- To calculate the expected flux of Planet Nine, we plotted the spectral radiance curve with different wavelengths by assuming that its temperature is 30 K, Bond albedo of 0.3 is similar to Uranus and Neptune.
- A research suggests the potential sky region to find Planet Nine, where $30° < RA < 50°, -20° < DEC < 20°$ [3].

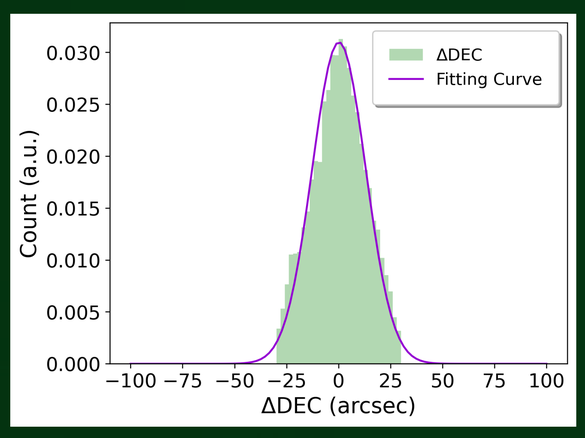
$M_{P9} = 5 \sim 17 M_{Earth}$, $d_{P9} = 1000 \sim 300\ AU$ → $Proper\ motion\ (over\ 23.4\ years) = 25 \sim 152\ arcmin$, $F_{90} = 0.007 \sim 0.081\ Jy\ (with\ M_{P9} = 17 M_{Earth})$

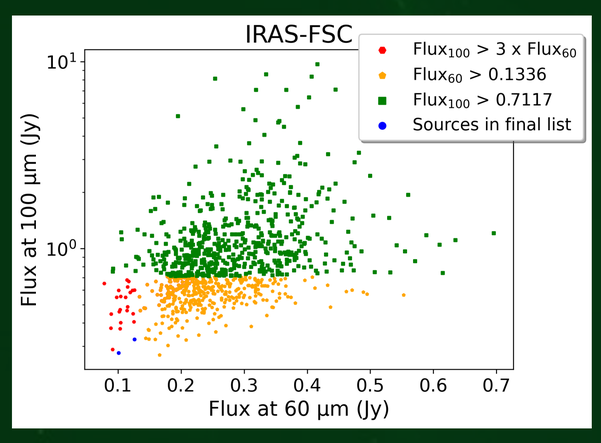
Results and Discussions

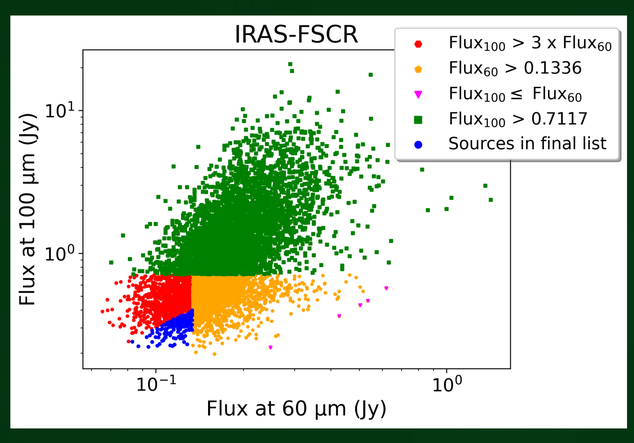


- One of crossmatch results including two histograms with Gaussian fitting curves and 2D scatter plot.
- $\sigma_{\Delta RA} = 13.93\ arcsec; \sigma_{\Delta DEC} = 12.88\ arcsec$
- Since our target is a planet, we expect it is a moving source over 23.4 years instead of a non-moving one. A radius of 2σ was selected to find and exclude matched sources in each pair of catalogues.
- After the crossmatching step, there are 23,061 sources excluded from the total of 1,746,321 sources.









1,103,044 sources

↓ Too close to galactic plane ($|b| < 10°$)

19,909 sources

$RA < 30°\ or\ RA > 50°$

$DEC < -20°\ or\ DEC > 20°$

↓

10,460 sources

↓ Flux slopes are too steep ($F_{90}/F_{65} > 3$, $F_{100}/F_{60} > 3$)

5,737 sources

Flux does not follow the above spectral radiance plot (Ex: F_{140}, $F_{160} > F_{90}$, etc.)

↓

1,194 sources

Flux excesses the limit of a potential planet ($M > M_{Jupiter}$)

➢ *List of criteria for position and flux selections. These criteria are based on the spectral radiance curve as well as the flux estimation for Planet Nine, and results from previous studies [2], [3], [4]. Sources would be excluded if they matched these criteria.*

- Two color-color diagram were plotted to visualize the flux selection of IRAS-FSC and IRAS-FSCR. All data points are sources after position selection (two first criteria).
- After flux selection, potential candidates are sources marked in blue. Total sources including AKARI and IRAS in the final list are 1,194 (1,028 AKARI sources, 164 IRAS-FSCR sources, and 2 FSC sources).
- The final list of potential candidates obtaining in this work strongly depends on the assumptions of Planet Nine such as mass, distance, temperature, etc.

Future Works

- In the next step, we plan to find the counterparts of 166 IRAS sources in AKARI catalog using the estimated proper motion and flux ratio between F_{90} and F_{100}. This step is necessary to identify the location of candidates after 23.4 years.
- Once all counterparts are found, we start to evaluate the cutout images of these candidates in detail.
- We can also reprocess this work by expanding the searching range of distance, mass or changing the expected temperature of Planet Nine.

References

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2. Sedgwick, C., & Serjeant, S. (2022). Searching for giant planets in the outer Solar system with far-infrared all-sky surveys. *Monthly Notices of the Royal Astronomical Society*, *515*(4), 4828-4837.
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4. Cowan, N. B., Holder, G., & Kaib, N. A. (2016). Cosmologists in Search of Planet Nine: The Case for CMB Experiments. *The Astrophysical Journal Letters*, *822*(1), L2.